Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Desalination 248 (2009) 144–151
DESALINATION
www.elsevier.com/locate/desal

# Factors supporting the sustained use of solar water disinfection – Experiences from a global promotion and dissemination programme

R. Meierhofer*, G. Landolt

*Swiss Federal Institute of Aquatic Science and Technology, Eawag, Department of Water and Sanitation in Developing Countries, Sandec Überlandstrasse 133, CH-8600 Dübendorf, Switzerland*
*Tel. +41 44 823 50 73; Fax +41 44 823 53 99; email: regula.meierhofer@eawag.ch*

Received 31 January 2008; revised accepted 15 May 2008

**Abstract**

Every year, 1.8 million people, mainly children under the age of five, die of diarrhoea. Point-of-use water treatment methods, such as solar water disinfection (SODIS), reveal a great potential to reduce the global diarrhoea burden. Comprehensive microbiological research demonstrated the effectiveness of SODIS to destroy diarrhoea-causing pathogens in contaminated drinking water. Since the year 2000, SODIS is being promoted in developing countries through information and awareness campaigns, training and advising of the public sector (government institutions), networking activities, as well as user training at the grassroot level. The method is currently used in 33 countries by more than 2 million people. Several project evaluations and health impact studies reveal that the diarrhoea incidence of SODIS users has dropped by 16–57%. One year after project implementation, 20–80% of the trained people used SODIS on a regular basis. This paper looks into factors influencing acceptance and sustained use of SODIS on grassroot level, i.e. local availability of bottles, repeated promotion and training programmes, motivation and commitment of promoters, educational level of users, social pressure, and institutional aspects.

*Keywords:* Solar disinfection; Drinking water treatment; Health education; Behavioural change; Sustained use

## 1. Introduction

Though water in sufficient quantity and good quality is essential for life, 17% of the global population or 1.1 billion people in 2002 lacked access to improved water supply and far more to adequate sanitation. This situation leads to a high risk for waterborne diseases such as diarrhoea, cholera, typhoid fever, hepatitis A, amoebic and bacillary dysentery as well as other diarrhoeal diseases. Every year, 1.8 million people, mostly in developing countries, die of diarrhoea, 90% are children under the age of five. This is equivalent to about 4500 children dying every day [1].

Public water supplies in developing countries often fail to produce and distribute water safe for consumption. Even if safe water is provided at the source,

* Corresponding author.

*Presented at the Water and Sanitation in International Development and Disaster Relief (WSIDDR) International Workshop Edinburgh, Scotland, UK, 28–30 May 2008.*

0011-9164/09/$– See front matter 
doi:10.1016/j.desal.2008.05.050

transport, storage and handling of water often lead to secondary contamination before consumption. Point-of-use water treatment methods are therefore gaining increased significance with regard to reducing the global diarrhoea burden [2]. Solar water disinfection (SODIS) proves to be a method with a great potential to reduce diarrhoea incidence among users.

## 2. Solar water disinfection – development of the method

Research on SODIS was first conducted by Professor Aftim Accra at the American University of Beirut in the early 1980s [3]. Follow-up research at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) revealed that at 30°C water temperature, a threshold solar radiation intensity of at least 500 W/m$^2$ (all spectral light) is required for 5 h for SODIS to be efficient. This dose corresponds to 5 h of mid-latitude midday summer sunshine. The investigations revealed that at 45°C water temperature, a synergistic effect of UV-A radiation and temperature decreases the required exposure time to attain a 4 log inactivation of faecal coliforms by 75% [4,13].

In the second phase of the research project, Eawag conducted field tests to evaluate various types of plastic and glass bottles, plastic bags, the influence of black and reflective support systems as well as applicability, acceptability, cost and handling aspects through users in the field. The following operating guidelines were defined for SODIS: microbiologically contaminated water is filled into transparent PET bottles of up to 3 L volume and exposed to full sunlight for 6 h. Two days of consecutive exposure are needed under more than 50% cloudy skies. As suspended solids block UV radiation, preliminary treatment is necessary if turbidity exceeds 30 NTU (sedimentation, flocculation, filtration) [5].

A large body of microbiological research followed, that assessed and demonstrated the effectiveness of SODIS in destroying diarrhoea-causing bacteria, viruses as well as *Giardia* spp. and *Cryptosporidium* spp. [7–16].

### 2.1. Health impact

The health impact of consuming SODIS-treated water was first examined in Kenya in the 1990s. The study conducted among Maasai children under the age of five showed a 16–24% diarrhoea reduction and a 86% reduction in cholera cases during an outbreak [17]. From 2000 to 2003, the Swiss Tropical Institute conducted an epidemiological study in Bolivia in collaboration with Eawag to assess the health impact of SODIS on children below five. According to the study, SODIS reduced diarrhoea incidence by more than 35% [18]. A health impact study carried out by the Department of Community Health of the Christian Medical College Vellore in India, and by the Section for International Maternal and Child Health, University of Uppsala in Sweden, among 100 children in an urban slum in Tamil Nadu, revealed that the risk of diarrhoea was reduced by 40% by using SODIS [19]. Further health evaluation studies were conducted during project implementation in the two cities of Rajoa and Chiniot in Pakistan in 2004. Diarrhoea incidence was reduced from 26% to 13% in Rajoa and from 39% to 19% in Chiniot [21]. From October 2003 to November 2006, diarrhoea incidence in Uzbekistan among children under the age of five was reduced by 53–57% [22,23]. Diarrhoea incidence also dropped by about 50% in projects conducted in Nepal, East Lombok and Assam, India (Project Reports).

### 2.2. Cost benefit aspects

The mean costs for SODIS implementation in 13 countries, including the costs for bottles and educational material amounted to annually USD 0.75 per trained person. In the following years, users pay on average USD 0.40 for the application of SODIS, i.e. to replace damaged bottles. The running costs for SODIS application are greatly outweighed by the economic benefits drawn from improved health as a result of reduced diarrhoea incidence, i.e. expenditure for medical care decreases, the economic productivity of adults' increases and the school attendance of children increases, which leads to additional benefits.

The health impact assessments in Pakistan, Uzbekistan, Nepal, East Lombok, and India, revealed that the diarrhoea rates of more than 970,000 SODIS users was reduced by about 50%. Therewith, an estimated 2.4 million diarrhoea cases could be prevented annually in the project areas. Assuming that treatment of one diarrhoea case costs the health sector USD 10 [24],

more than USD 24 million were saved by the health sector. Moreover, the benefit of an improved economic labour force through improved health is estimated at USD 12 million [24]. With a total project cost of USD 730,800, the achieved cost–benefit ratio for the health sector amounted to 1:49!

At household level, the cost–benefit ratio is not as dramatic, but still significant: SODIS users in Nepal and Pakistan in average save 32 USD, respective 22 USD, annually per household through reduced cost for the medical treatment of diarrhoea. In the Kibera Slum of Nairobi, Kenya, a household annually saves 7 USD in average through reduced cost for the medical treatment of diarrhoea. The annually recurring cost for the PET bottles needed by one household for the SODIS application are 2.20 USD in Nepal and Pakistan and 3.20 USD in Kenya. Data on the benefits of the improved labour force have not been collected at household level.

## 3. Intervention strategies used for dissemination of SODIS

Based on the insights gained during the field-testing of SODIS, Eawag/Sandec started in 2000 the SODIS promotion and dissemination campaigns in selected developing countries. In collaboration with local partner organisations, mainly NGOs experienced in health education, pilot projects were formulated to educate users at the grassroot level in SODIS application. Implementation programmes, generally lasting for about 12 months, were formulated after assessing the need to introduce SODIS and determining suitable local conditions for SODIS promotion. The need assessment focuses on the following aspects: need for water treatment, health status of the local population, climatic conditions, bottle availability, felt need for clean water, potential for networking of the partner organisation, and potential for scaling up. Follow-up projects in neighbouring areas were formulated based on the results obtained in the previous phase.

The implementation strategy was formulated in a joint exercise with Eawag/Sandec. Local partners followed their own approach in their field of expertise, but received advice from Eawag/Sandec in strategic planning and capacity building on technical aspects (Table 1) [6].

### *3.1. From working with NGOs towards partnership with governments*

Working through NGOs during the start-up of activities in a country proved to be quite effective as their management structures are lean and flexible and sound results can be obtained in the field within a relatively short time. Though the collaboration with NGOs can produce quick results in a confined area, the sustained activity of the organisation is dependent on available external funds. The potential for upscaling SODIS dissemination at national level therefore relies on the funds available.

Evidence of health improvements among SODIS users trained by the NGO partners is an excellent tool to support advocacy activities with national governments and official institutions. The strength of a collaboration with government institutions is the continuous operation of the extension services of the health, education and water supply sectors, which have a great potential to reach a large number of people. Moreover, the normative functions of institutional bodies facilitate the promotion of SODIS at grassroot level, as these can officially sanction a method or an approach. Official statements and policies provide credibility, and programme sustainability is strengthened if it forms part of the national extension and education plan.

During 2000 and 2005, the SODIS promotion and dissemination programme focussed on a collaboration with NGOs as partners for SODIS implementation. Since then a gradual shift has taken place to increase collaboration with government institutions. Official institutions are directly involved in implementing SODIS projects in Pakistan, Nepal, Uzbekistan, Indonesia, Vietnam, Philippines, Bhutan, Ecuador, Bolivia, Nicaragua, Honduras, Guatemala, and El Salvador.

Project evaluations of the SODIS implementation in 18 countries and two socio-scientific assessments [26,27] reveal that a sustainable spread of the method is dependent on the promotion approach. One year after project implementation, 20–80% of the trained people used SODIS on a regular basis. This variation in actual acceptance and use of the method has prompted us to conduct a more detailed study of the factors influencing the sustained use of SODIS at grassroot level.

The insights presented in the following chapter on the factors influencing the sustained use of SODIS, are

Table 1
Interventions used for diffusion and promotion.

| |
|---|
| Information campaigns |
| • Promotion and information campaigns using the local mass media (TV, radio, newspapers) |
| • Public exhibitions and demonstrations at markets, in front of health posts |
| • Street plays |
| • SODIS entertainment night with songs, karaoke and theatres |
| • Public display of posters and prompts in the project area |
| • Poster designing competitions |
| Advocacy |
| • Advocacy through involving and convincing opinion leaders |
| • Submitting evidence of the project impact to local authorities |
| • Creation of involved stakeholder networks (NGOs and official institutions from the health, education and water supply sectors, universities, international organisations) |
| • Setting up mechanisms to facilitate the exchange of information, such as regular meetings, workshops, electronic exchange of information |
| • Performance of water quality tests in front of the community |
| Training of users |
| Training and promotion of SODIS and hygiene at grassroot level through promoters (staff of a local NGO, health workers, community volunteers): |
| • Raising awareness and behavioural change via participatory methods (such as PHAST, Participatory Hygiene and Sanitation Transformation) |
| • Use of locally adapted training material (posters, flyers, pamphlets, calendars) |
| • Training during group and community gatherings (mothers' groups, youth groups etc.) |
| • Regular household visits |
| • Promotion through schools |

based on half-yearly project evaluations in Nepal, India, Pakistan, Uzbekistan, Indonesia, Kenya, Uganda, Bolivia, Nicaragua, Peru, Ecuador, Guatemala, Honduras, and El Salvador and on two socio-scientific assessments.

## 4. Factors influencing the sustained use of SODIS at grassroot level

### *4.1. Availability of bottles*

Local availability of the required bottles (PET or glass) is crucial for sustainability of SODIS application. In many areas, accessibility of PET bottles is the limiting factor for the continued application of SODIS. Creation of a micro-enterprise to secure the supply of bottles appears to be the solution to address the lack of PET bottles in some areas. East Lombok is a successful example of a bottle supply scheme. During project implementation, the health system set up a supply scheme, which buys empty bottles from the PET-bottle producer and sells them to the users at the health posts.

### *4.2. Single information events are not sufficient to achieve a behavioural change*

Habits are hard to change. Interventions with just one information event are not sufficient to establish a sustainable SODIS practice [25]. A long-term intervention with promoters visiting trained users regularly over several months after initial training is required to raise awareness and establish a sustainable practice.

### *4.3. Motivated promoters play a key role*

Local SODIS promoters play a key role regarding acceptance and use of SODIS at grassroot level.

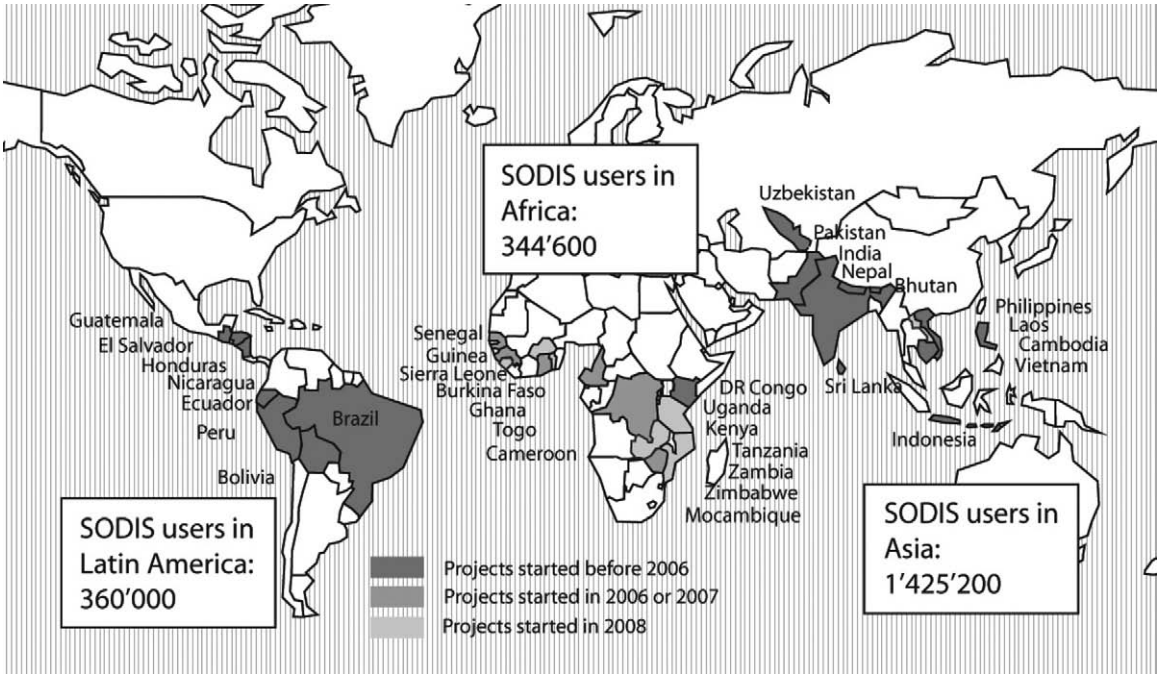


Fig. 1. More than 2 million users currently practise SODIS in 33 countries.

SODIS practice was the highest in villages where locally respected people worked as highly motivated and convinced promoters.

According to a socio-scientific study on the effectiveness of different SODIS dissemination strategies in Bolivia, the promotion of SODIS by skilled staff of local authorities or skilled staff of the local NGOs was most convincing. Users favoured the health fair for training, as it offers the possibility to discuss the subject with others and takes place in a relaxed and friendly atmosphere [26].

Another field study in Nicaragua revealed that the intention to use SODIS and the actual use of SODIS are mainly related to an overall positive attitude. Well-designed promotion activities, particularly by choosing highly motivated promoters, who are able to inspire confidence in the new technology, positively influence uptake and use of the method [27].

This finding is confirmed by the results of the SODIS implementation project in Uzbekistan. SODIS acceptance and use by the local population was greatly dependent on the motivation and initiative of key officials in the field. Users in the rural community also accepted SODIS more readily if the method was introduced by the official health workers rather than by the NGO staff who originally initiated the SODIS pilot activities in Uzbekistan [23]. The influence of the promoters is reflected in the health impact assessment conducted in the project areas in November 2006: the highest SODIS adoption rate was found in the Burkhara (50%) and Sirdaryo Provinces (75%), where a reduction in diarrhoea incidence of 57% in just one year was achieved. The control group in the same region reported a comparatively smaller reduction in diarrhoea of only 7%. SODIS use and also diarrhoea reduction were much lower in the two other project regions of Karakalpakstan and Ferghana. The project team attributes this difference in the uptake of the method and related health impact to the highly committed official field staff in the Sirdaryo and Burkhara Province [22].

Similarly, direct observations of the author during a project mission to Nepal in November 2007 revealed that a highly motivated and committed Health Volunteer in Thimi was able to motivate 80% of the population in her working area to use SODIS, whereas other

volunteers in the same city reached about 50% SODIS use in their respective working zones.

### 4.4. Education level influences willingness to change behaviour

Initially, more highly educated people, such as teachers, health workers or village leaders, were more difficult to convince that SODIS can efficiently treat drinking water. Bacteriological water quality tests with raw water and treated water were effectively used to reduce scepticism about the microbiological efficiency of the method. Field observations in Bolivia and Nepal as well as a project evaluation in Kenya revealed that once doubts on SODIS efficiency are dispelled, people with a higher education and higher economic status are more likely to adopt SODIS, improve their hygiene behaviour and also sustain it over a longer period [20].

### 4.5. Social pressure influences behaviour

SODIS acceptance is more prominent in areas where SODIS is clearly visible in the community (many bottles on the roofs or in front of the houses) and used by a great number of people, including the community leaders. The observations made in several project areas are confirmed by the field study conducted in Nicaragua, which shows that the intention to use SODIS is related to the use of SODIS by neighbours [27]. Different tools can be used to enhance the visibility of SODIS in a project area: dissemination of messages through mass media (TV, radio, etc.), display of posters in prominent areas of the community, public exhibitions, and the display of prompts (signs at the entrance of the house, indicating that this household is using SODIS for drinking water treatment).

### 4.6. Integration of SODIS into programs of the governmental institutions

A field study of the co-author in Bolivia in 2007 on aspects of sustainability revealed that the integration of SODIS education into official institutions support the continued dissemination and promotion of SODIS at grassroots level. The structure and regular operation of the official extension services have a great potential to reach many people.

At local level however, government institutions faced a frequent turn over of staff. Know-how and capacity frequently was lost due to the transfer of key personnel. The collaboration with Government institutions therefore cannot only focus on a partnership with institutions at local level such as schools, health posts, municipalities, district offices, but the discussion with normative bodies in the health, education and water supply sector at central level was essential for the sustainable integration of SODIS into government programs. The official bodies at higher level can sanction a method or an approach and formulate extension policies and education curricula that outlive the frequent turn over of staff at local level. In addition, the integration of SODIS into national health and education campaigns enhance the credibility of the messages.

The institutionalization of SODIS and its integration into government structures is a process that needs time. Where the uptake of SODIS dissemination through national Governments has taken place, it is a result of several years of work at grassroots level in partnership with local NGOs or local government entities (schools, health posts, municipalities, district offices). Such a long-term collaboration allows project partners to create evidence on the health impact of SODIS under local conditions and present it to the authorities.

The co-author concluded that through project partners that integrated the SODIS messages into regular programs and local institutions (schools, health centres, local and superior governmental structures), a higher level of institutionalization, continuation and extension of the SODIS promotion and a positive effect on the sustained use of SODIS at household level could be observed.

## 5. Conclusions

SODIS is currently used in 33 countries (Figure 1). The results obtained are based on the experience gained in 18 countries where dissemination projects were implemented under different conditions. Health impact evaluations in eight countries revealed that the method has a great potential in reducing diarrhoea (between 16% and 57%). Therefore, the economic cost–benefit project ratio amounts to about 1:49.

A large variation in the uptake and sustained use of the method in the range of 20–80% was observed at grassroot level and can be attributed to the different circumstances encountered during project implementation in the 18 countries. A widespread dissemination and sustained use of the method can be reached if the carriers of the message – the promoters – are convincing, committed and respected persons, if enough bottles are available for the sustained application, several training events are conducted, if the method is practised by many other users and thus clearly visible, if implementation strategies are tailored to the education level of the recipients, if a health improvement is felt by users, and if the institutional setup and official backup of the method is supportive.

## References


[1] WHO, Database on Water, Sanitation, Hygiene, 2004.

[2] L. Fewtrell, R.B. Kaufmann, D. Kay, W. Enanoria, L. Haller and J.M. Colford Jr., Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis, Lancet Infect. Dis., 5 (2005) 42–52.

[3] A. Acra, Y. Karahagopian, Z. Raffoul and R. Dajani, Disinfection of oral rehydration solutions by sunlight, Lancet, 316(8206) (1980) 1257–1258.

[4] M. Wegelin, S. Canonica, K. Mechsner, T. Fleischmann, F. Pesaro, A. Metzler, et al., Solar water disinfection: scope of the process and analysis of radiation experiments, J. Water SRT, Aqua, 43(4) (1994) 154–169.

[5] R. Meierhofer, Solar Water Disinfection, A Guide for the Application of SODIS, Eawag/Sandec, Dübendorf, 2002, http://www.sodis.ch/files/SODIS_Manual_english.pdf.

[6] R. Meierhofer, Training Manual for SODIS Promotion, Eawag/Sandec, Dübendorf, 2006, http://www.sodis.ch/files/TrainingManual_sm.pdf.

[7] B. Sommer, A. Mariño, Y. Solarte, M.L. Salas, C. Dierolf, C. Valiente, D. Mora, R. Rechsteiner, P. Setter, W. Wirojanagud, H. Ajarmeh, A. Al-Hassan and M. Wegelin, SODIS – an emerging water treatment process, J. Water SRT, Aqua, 46(3) (1997) 127–137.

[8] K.G. McGuigan, T.M. Joyce, R.M. Conroy, J.B. Gillespie and M.I. Elmore-Meegan, Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation process, J. Appl. Microbiol., 84 (1998) 1138–1148.

[9] R.J. Smith, S.C. Kehoe, K.G. McGuigan and M.R. Barer, Effects of simulated solar disinfection on infectivity of Salmonella typhimurium, Lett. Appl. Microbiol., 31(4) (2000) 284–288.

[10] S.C. Kehoe, T.M. Joyce, P. Ibrahim, J.B. Gillespie, R.A. Shahar and K.G. McGuigan, Batch process solar disinfection is an efficient means of disinfecting drinking water contaminated with Shigella dysenteriae Type I, Lett. Appl. Microbiol., 38 (2004) 410–414.

[11] F. Méndez-Hermida, J.A. Castro-Hermida, E. Ares-Mazás, S.C. Kehoe and K.G. McGuigan, Effect of batch-process solar disinfection on survival of *Cryptosporidium parvum* oocysts in drinking water, Appl. Environ. Microbiol., 71(3) (2005) 1653–1654.

[12] K.G. McGuigan, F. Méndez-Hermida, J.A. Castro-Hermida, E. Ares-Mazás, S.C. Kehoe, M. Boyle, C. Sichel, P. Fernández-Ibáñez, B.P. Meyer, S. Ramalingham and E.A. Meyer, Batch solar disinfection (SODIS) inactivates oocysts of *Cryptosporidium parvum* and cysts of *Giardia muris* in drinking water, J. Appl. Microbiol., in press.

[13] M. Berney, H.-U. Weilenmann, A. Simonetti and T. Egli, Efficacy of solar disinfection of *E. coli, S. flexneri, S. typhimurium* and *V. cholerae*, J. Appl. Microbiol., 101 (2006) 828–836.

[14] M. Berney, H.-U. Weilenmann and T. Egli, Flow-cytometric study of vital cellular functions in *Escherichia coli* during solar disinfection (SODIS), Microbiology, 152 (2006) 1719–1729.

[15] W. Heaselgrave, N. Patel, S.C. Kehoe, S. Kilvington and K.G. McGuigan, Solar disinfection of poliovirus and *Acanthamoeba polyphaga* cysts in water – a laboratory study using simulated sunlight, Lett. Appl. Microbiol., 43(2) (2006) 125–130.

[16] M.R. Gaafar, Effect of solar disinfection on viability of intestinal protozoa in drinking water, J. Egypt. Soc. Parasitol., 37(1) (2007) 65–86.

[17] R.M. Conroy, M.E. Meegan, T.M. Joyce, K.G. McGuigan and J. Barnes, Use of solar disinfection protects children under 6 years from cholera, Arch. Dis. Child, 85 (2001) 293–295.

[18] M. Hobbins, The SODIS Health Impact Study, Ph.D. Thesis, Swiss Tropical Institute Basel, 2003.

[19] A. Rose, S. Roy, V. Abraham, G. Holmgren, K. George, V. Balraj, S. Abraham, J. Muliyil, A. Joseph and G. Kang, Solar disinfection of water for diarrhoeal prevention in Southern India, Arch. Dis. Child, 91(2) (2006) 139–141.

[20] J. Graf, The Effects of SODIS and Hygiene Behaviour on Diarrhoea Cases Among Young Children in the Kibera Slum, A Quantitative Field Study About Water Consumption and Hygiene in Nairobi, Kenya, Project Report Eawag/Sandec, Dübendorf, August 2006.

[21] S. Gamper, Acceptance, Use and Health Impact of Solar Water Disinfection, A Case Study from Rajoa and Chiniot, Eawag/Sandec, Dübendorf 2004.
[22] B. Grimm, Bottles for Our Health, Report of the SODIS Dissemination Project, Phase II: April 2003–March 2004, JDA, Kokand, 2004.
[23] B. Grimm, SODIS Health Impact Study, Uzbekistan, 2004–2006, JDA Kokand, November 2006.
[24] L. Haller and G. Hutton, Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level, WHO, Geneva, 2004.
[25] R.C. Rainey and A.K. Harding, Acceptability of solar disinfection of drinking water treatment in Kathmandu Valley, Nepal, Int. J. Environ. Health Res., 15(5) (2005) 361–372.
[26] S. Moser, S. Heri and H.J. Mosler, Determinants of the Diffusion of SODIS, A Quantitative Field Study in Bolivia, Summary Report, Eawag, Dübendorf, 2005.
[27] A.M. Altherr, H.J. Mosler, R. Tobias and F. Butera, Attitudinal and relational factors predicting the use of solar water disinfection. A field study in Nicaragua, Health Educ. Behav., accepted for publication.